Magma-Metal Series Classification of Mineralization in the Vicinity of Yucca Mountain, Nevada

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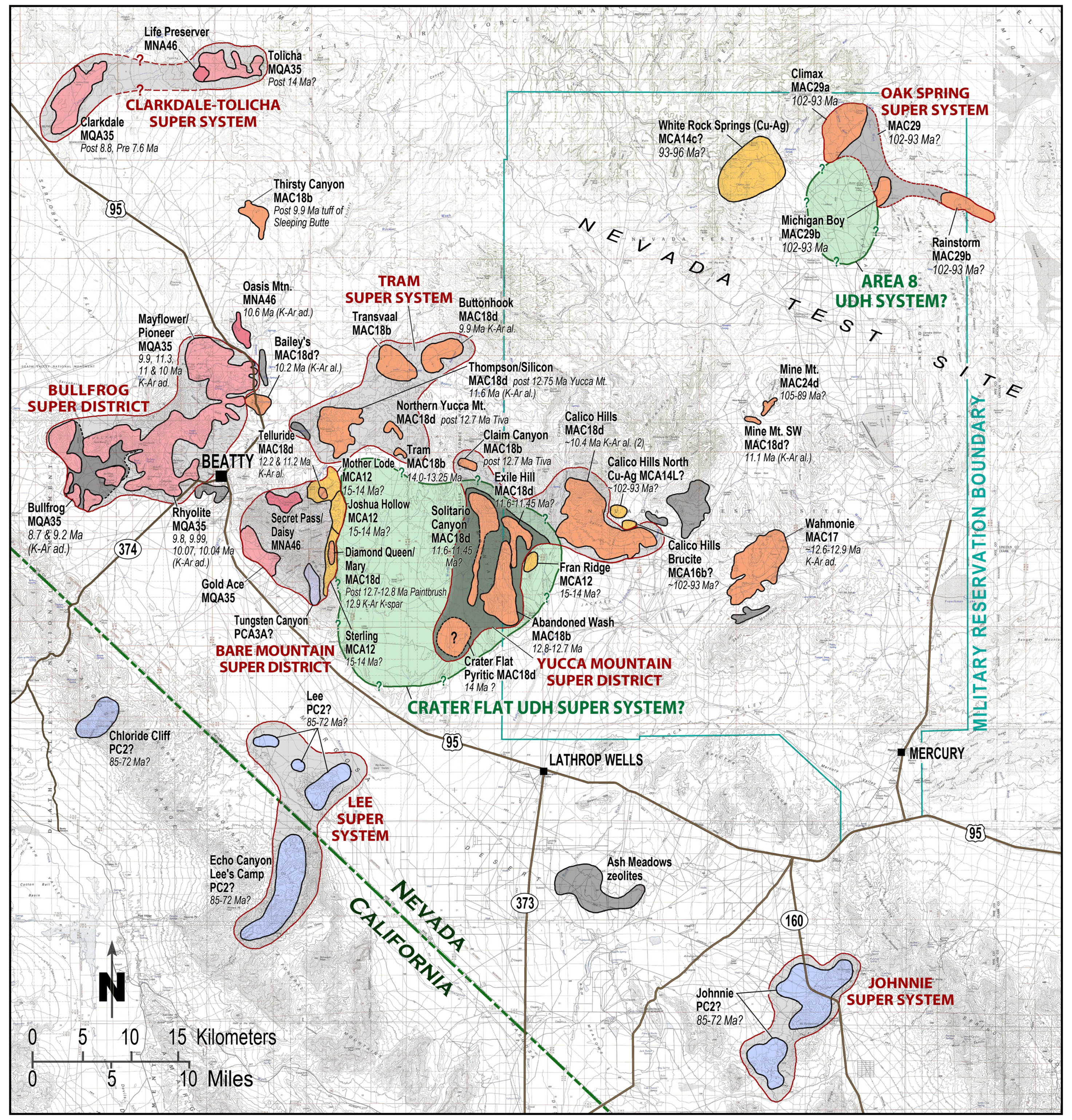
Mineral Districts in Vicinity of Yucca Mountain, Nevada



ABSTRACT

This paper applies the magma-metal series classification developed by Keith and others (1991) and Keith and Swan (1996) to mineralization of southwestern Nevada, including the Nevada Test Site (NTS), Yucca Mountain, and surrounding areas. The new Ultra-Deep Hydrocarbon (UDH) hydrothermal oil model (Keith and others, 2008) also applies to the region. Mineralization was emplaced from mid-Cretaceous to late Miocene time. Mineralization related to the Miocene volcanism at Yucca Mountain did not contain enough hydrous minerals to suggest there was potential for economic mineralization.

The Cretaceous magmatism and related mineralization in the NTS region include: 1) the Climax stock (metaluminous alkali-calcic [MAC]) at 102 – 99 Ma; 2) the Gold Meadows stock (metaluminous calc-alkalic [MCA]) at 93 – 96 Ma, which can produce copper-molybdenum-silver porphyry systems; 3) peraluminous calcic (PC) tungsten associated with pegmatite dikes (PC2 of Late Cretaceous age); and 4) peraluminous calc-alkalic (PCA3A) gold-quartz veins at 85 – 72 Ma.

The Cretaceous MAC and MCA magmatism reflects flattening subduction between 100 and 90 Ma. The main structures that accompanied metaluminous magmatism were east-directed thrust faults (e.g., the Belted Range thrust) that were broadly related to the Sevier orogeny in eastern Nevada and western Utah.

The peraluminous magmatism probably resulted from flat subduction beneath the region between 90 and 72 Ma. Structures related to this flat subduction include west-directed mylonite fabrics in low-angle thrust faults related to peraluminous sills in northern Bare Mountain and south of Beatty, and possibly to the WNW-directed CP thrust east of Yucca Mountain.

Tertiary mineralized systems in the region are metaluminous and include: 1) calc-alkalic [MCA] gold mineralization at13.8 – 14.9 Ma; 2) alkali-calcic [MAC] base-metal mineralization of the central arc at 12.8 – 11.2 Ma; 3) quartz-alkalic [MQA] gold mineralization of the late arc at 10 Ma; and 4) nepheline alkalic [MNA] gold-telluride mineralization of the terminal arc at 8 Ma. The increasing alkalinity with decreasing age reflects a rapidly steepening subducting slab beneath the Yucca Mountain area between 15 and 7 Ma.

The MCA gold mineralization of the early Miocene arc includes mines on the east flank of Bare Mountain and Paleozoic-hosted mineralization presently deeper than 4800 feet at Yucca Mountain. Examples include Sterling and Mother Lode on the east side of Bare Mountain.

Most of the Miocene igneous rocks in and near the Nevada Test Site are associated with the Southwest Nevada Volcanic Field erupted from 17 to 7 Ma. Most of the volume of volcanic rocks at Yucca Mountain is MAC magma-metal series, which is associated with lead-zinc-silver-tin mineralization throughout the world. The MAC volcanism and associated base-metal mineralization are related to the central part of the magmatic arc. These MAC districts include: silver-base metal mineralization at 12.6 – 12.8 Ma of the Wahmonie district; hot spring and probable epithermal tin mineralization at 13.5 – 12.7 Ma in the Beatty Mountain sinter area, Thirsty Canyon - Sleeping Butte area, and West Transvaal district; mercury/fluorite/alunite mineralization at 12.9 – 11.2 Ma in the northern Bare Mountain area, Mary/Diamond Queen mine, Telluride mine, Southern Calico Hills, western Calico Hills, Claim Canyon mercury anomaly areas, Transvaal East district; and widespread pyritic mineralization in the Tram Ridge Tuff, southwestern Mine Mountain, northern Yucca Mountain area.

The last major Miocene mineralization in the Yucca Mountain area is associated with quartz alkalic (MQA) magmatism in the trailing portion of the southward-migrating magmatic arc. MQA gold districts include gold-only/adularia mineralization at 10 Ma in the West Bare Mountain, and Bullfrog district [Bullfrog mine, Montgomery-Shoshone mine, Bonanza Mountain area, Original Bullfrog mine, Gold Bar mine, Mayflower-Pioneer area], Clarkdale district, and Tolicha district.

The latest metallic mineralization event was the basanitic, nepheline alkaline (MNA) volcanism associated with minor volumes of gold/telluride mineralization. These systems are dated at about 7 Ma in the Beatty area and possibly at the Oasis Mountain gold-telluride system.

The calderas and associated mineralization were probably emplaced in a transpressional regime that affected right slip on the Walker Zone to the north and on the Las Vegas Shear Zone – Stateline-Pahrump fault on the south. These two systems are connected by a north-south trending, dilational jog that includes most of the calderas. This area also includes a N-S trending normal-fault swarm and the north-south trending, Kawich-Greenwater gravity low. Extension in the dilatant jog created most of the room into which calderas and associated hydrothermal activity were emplaced. Minor antithetic tilting on the N-S faults (especially on Bare Mountain) created a gravitational ramp where local gravitational sliding occurred in the Bullfrog Hills tilt domain. The denudational sliding re-used pre-existing, low-angle thrust faults that had accompanied Cretaceous magmatism.

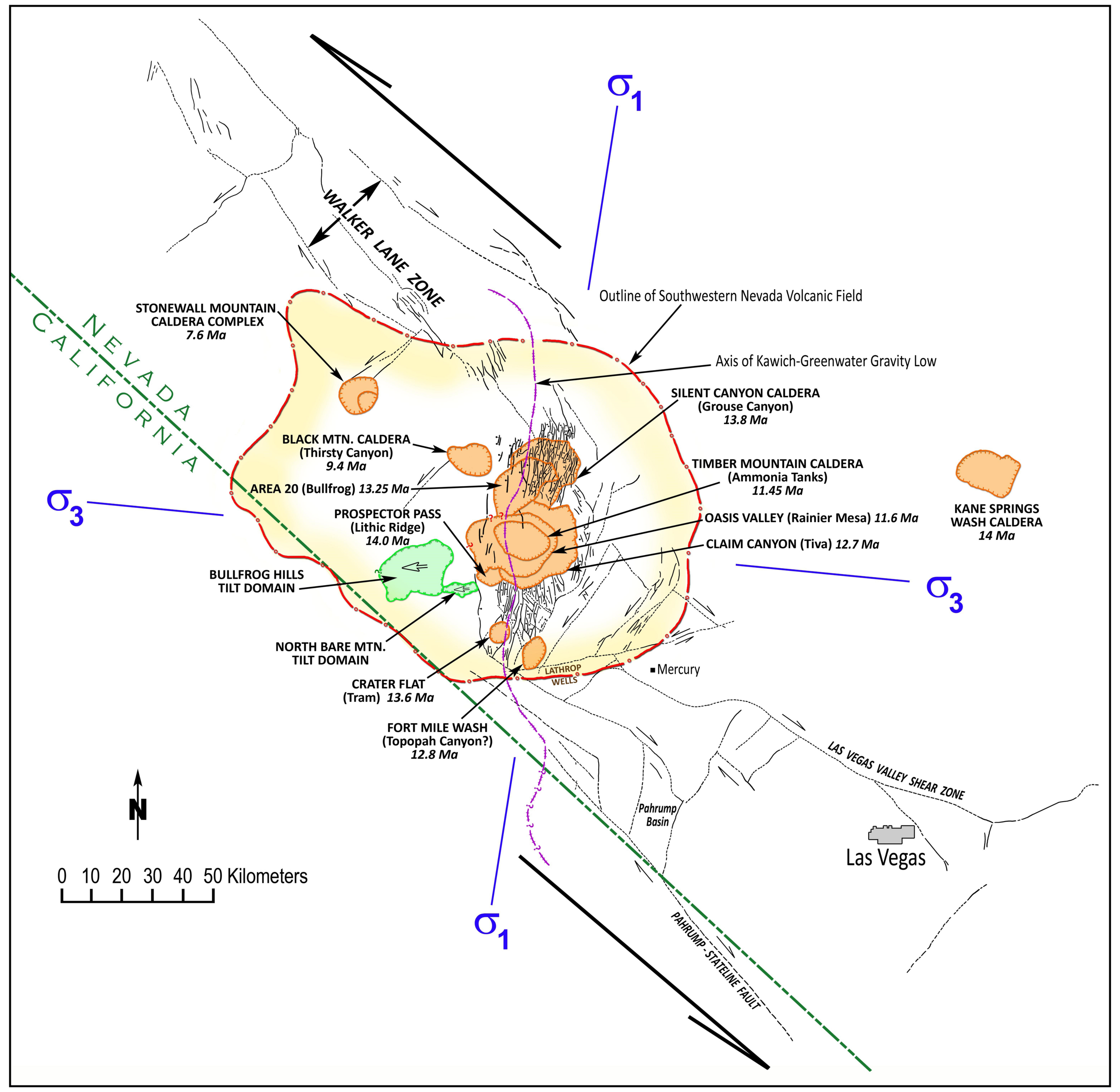
Between 7 and 4 Ma, the hydrous, iron-poor, metal-bearing magmatism changed to anhydrous, iron-rich, non-metallic magmatism. After 4 Ma, magmatism at Crater Flat contains anhydrous ferromagnesian minerals (such as olivine and pyroxenes), has no epigenetic mineralization, and has strong iron enrichment in typically low-volume felsic differentiates. The basaltic volcanism is associated with Basin and Range, high-angle, normal faults that are in a transtensional regime driven by far-field extension. In contrast, the earlier arc-related tectonism was driven by far-field transpression.

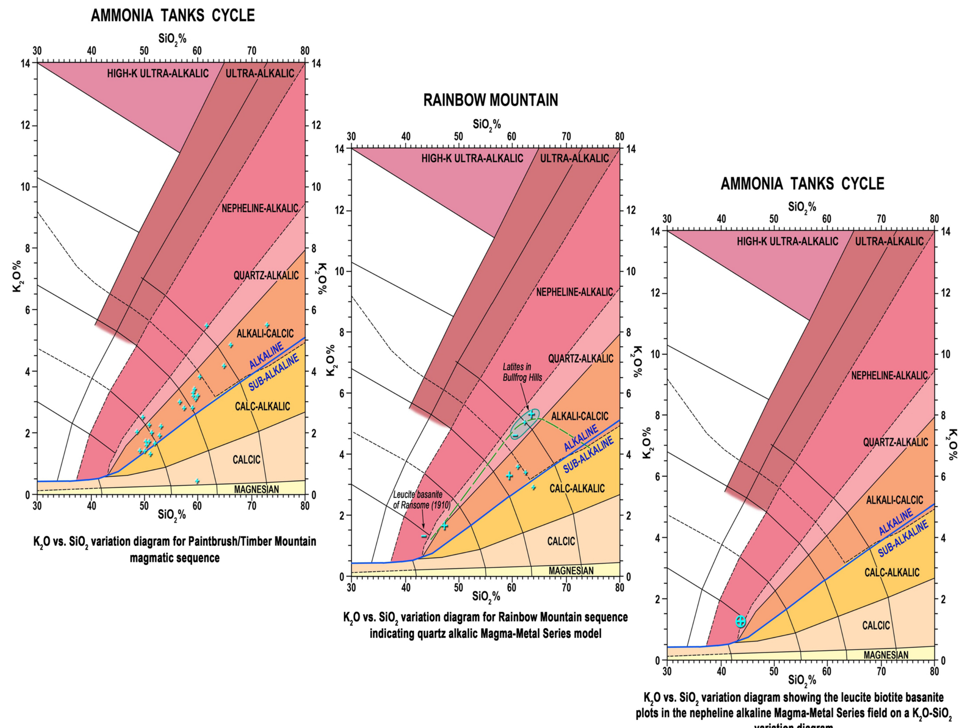
The youngest, most widespread hydrothermal activity in the Yucca Mountain area may be associated with hydrothermal oil developed from ultra-deep sources associated with serpentinization in the lower crust. Railroad Valley is the closest system that may be an example of this process. Evidence for this hydrothermal activity include basaltic volcanism at Crater Flat, extensive dolomitization in the Paleozoic carbonates beneath the Tertiary rocks, and widespread, magnesium-charged, light $\delta^{13}C$ isotopes, and warm (25 – 35°C) water discharge throughout the Yucca Mountain area. These features are consistent with a UDH, hydrothermal oil system that could underlie Crater Flat beneath a coinciding magnetic high and gravity low.

Magma-metal series models, timing, and magma types in the broader Nevada Test Site

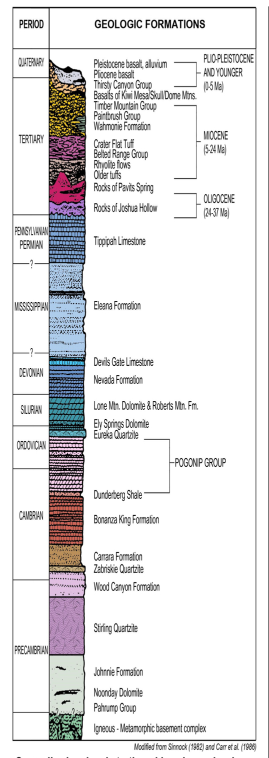
MAGMA-METAL CLASS	AGE (Ma)	METALS	CHARACTER	EXAMPLES
UDH?	Post-5	None	Basin and Range basalts; no biotite;	Thirsty Mesa; basalt of Armagosa Valley; basaltic andesite of Buckboard Mesa; Quaternary basalt of Crater Flat; basalt of Sleeping Butte and Lathrop Wells volcanic center
MNA46	< 8.7	Au-Te-Th-F-LREE, Mo-U	Terminal arc magmatism: leucite	Northern Bare Mountain (Daisy mine); Oasis Mountain area; central Clarkdale area; north of Rainbow Mountain; north of Montgomery Mountain; Life Preserver mine in Tolicha district
MQA35	10	Epithermal Au-Ag-Be-F, Au in qtz. veins in NNW faults, electrum, adularia, sericite; low As,Sb,Hg,Tl	Rainbow Mountain sequence	Bullfrog district (Bullfrog, Montgomery-Shoshone, Original Bullfrog; Gold Bar, Mayflower-Pioneer mines); Bonanza Mountain area; Clarkdale and Tolicha districts
MAC18B	11.4	Sn/polymetallic; sparse fluorite, qtz-calcite vnlets w/As, Sb, Hg, Tl	Fleur de Lis cycle in Paintbrush/ Timber Mountain Sequence	Mafic magmas; Dome Mountain; Fleur de Lis Ranch area; Sleeping Butte; Transvaal Hills
MAC18D	11.45	Hg-Li-F; alunitic alteration	Ammonia Tanks cycle in Paintbrush/ Timber Mountain Sequence	Buttonhook Wash; Mine Mountain southwest; Calico Hills; Fatigue Wash area?; Solitario Canyon area; associated with magnetic highs
MAC18D	11.6	Moderately productive Au-Ag in Bullfrog Hills; Hg-Li-F; Ba, alunite, Th?	Rainier Mesa cycle in Paintbrush/ Timber Mountain Sequence	Bulfrog Hills landslide mass; altered areas above, south or east of magnetic high anomalies
MAC	12.8-12.7	No metals	Tiva cycle in Paintbrush/Timber Mountain Sequence	From Claim Canyon caldron
MAC18B	12.8	Hot spring Sn; distal zone Zn-Tl-Bi-Pb-F-Ga-As-polymetallic	Topopah Spring cycle in Paintbrush/ Timber Mountain Sequence	Quartz latite member of Topopah Spring Tuff is associated with fault-related, hot spring vents (Abandoned Wash)
MAC17?	12.9-12.7	Elevated trace Ag, As, Au, Bi; moderately elevated Li, weakly elevated W, Zn, Sb, Pb, Hg, Se, Sn?	post-Wahmonie cycle in Paintbrush/ Timber Mountain Sequence	Altered area in Wahmonie Formation; sugestive of epithermal Ag veins; adularia dated at 12.6 ± 0.4 and 12.9 ± 0.4
MAC18B	<13.25	Zeolite-clay alteration; veins of specular hematite or Mn oxide locally; pyrite, barite locally present	post-Prow Pass cycle in Paintbrush/ Timber Mountain Sequence	Vein-type mineralization cutting units below the Calico Hills unit in boreholes in Yucca Mountain
MAC	13.25	---	Bullfrog Tuff cycle in Paintbrush/Timber Mountain Sequence	
MAC18B	14-13.25	Hot spring Sn mineralization: weak As, Bi, Zn, W, Li, Pb, Sb, Tl, LREE	Tram cycle in Paintbrush/Timber Mountain Sequence	Northern Yucca Mountain, Tram-Bullfrog contact
MAC18B?	14	Zeolite clay alteration; illite/ smectite ± albite ± adularia ± chlorite ± sericite ± hematite ± MnO	Lithic Ridge cycle in Paintbrush/ Timber Mountain Sequence	Pyritic mineralization in the Tram Tuff
MAC	15.25-14.9	None; small volume ash flows		Redrock Valley Tuff; tuff of Yucca Flat; Tub Spring Tuff, Tunnel Formation
MCA12	13.8-14.9, dikes; 17-14	Au, As, Sb, Hg, Tl, Se, Te; sediment hosted Au	Early Miocene	Eastern Bare Mountain, Sterling, Mother Lode, Diamond Queen mines, Joshua Hollow prospect; Yucca Mountain well EU-25 p#1 at 4858 ft in Silurian Lone Mountain Formation
PC2	90 - 72 ?	Au-qtz veins	Cpy, gal, hem	Trappmans district, Manhattan, Silver Peak district, Mineral Ridge (Mary Mine), Chloride Cliff and Lee districts
PCA3A	98 ± 27	W	Peraluminous granite	Tungsten Canyon, Fluorspar Canyon in southern Bare Mountain, Funeral Range
MCA16B?		Brucite	Brucite skarn	Calico Hills brucite
MCA14L?		Cu-polymetallic-Ag	Stage 4, porphyry Cu?	Northern Calico Hills
MCA14C?		Cu, Mo, Ag	Porphyry Cu-Mo?	Gold Meadows stock near White Rock Springs Cu-Ag mineral system
MAC29B	102 - 99	Ag, Pb, Zn, Cu, Mo, W	Pb-Ag polymetallic veins in faults in Paleozoic sedimentary rocks	Climax stock, Twin Ridge plutons, Oak Springs super-system

Structural Regimes in Vicinity of Yucca Mountain, Nevada





K₂O vs. SiO₂ variation diagram showing the leucite biotite basanite plots in the nepheline alkaline Magma-Metal Series field on a K₂O-SiO₂ variation diagram



Modified from Sinnock (1982) and Carr et al. (1986)

Generalized regional stratigraphic column showing geologic formations and hydrological units in the Nevada Test Site area (modified from DOE 95a). The repository host rock at Yucca Mountain is in the Tertiary age Paint Brush Tuff.

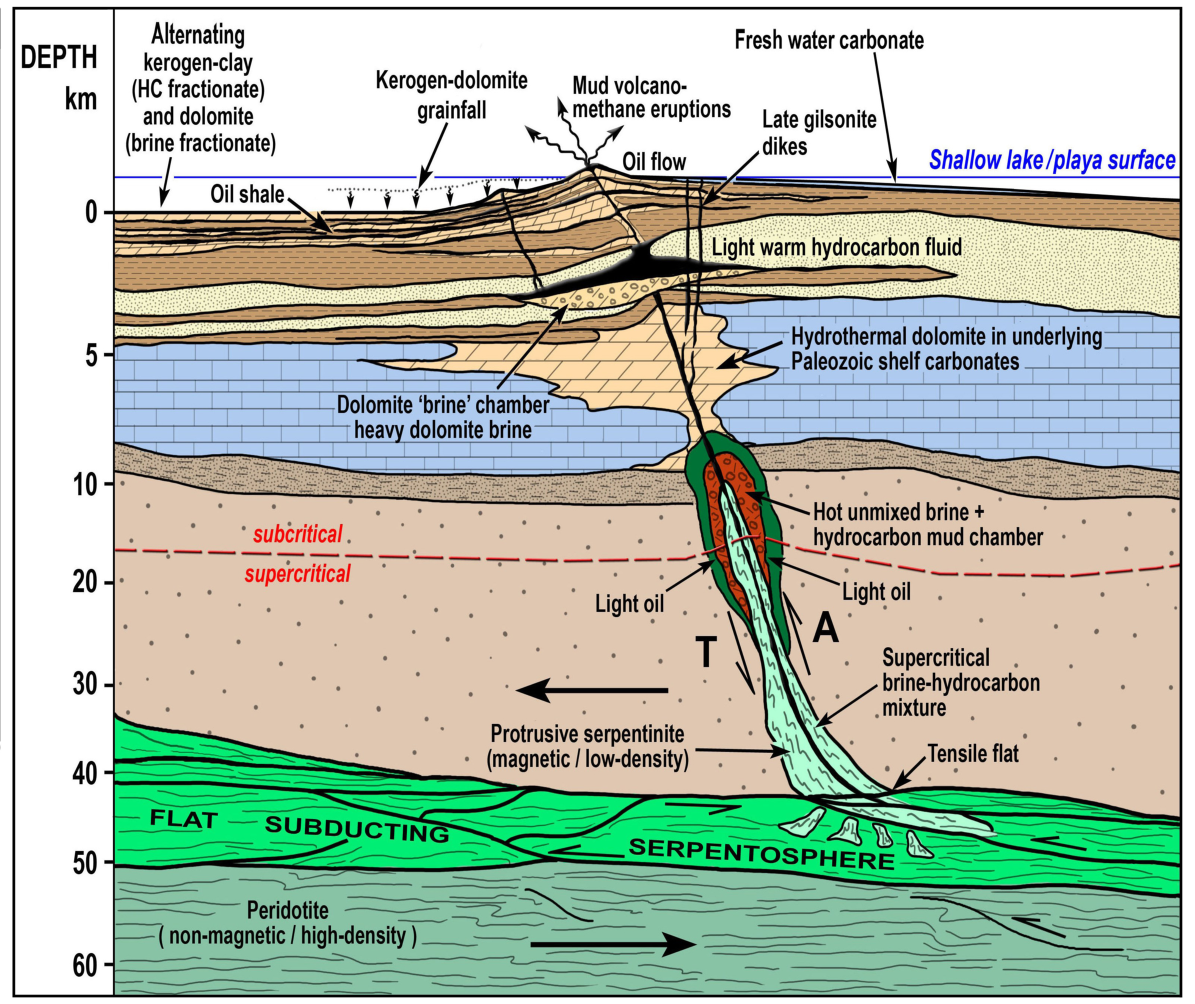
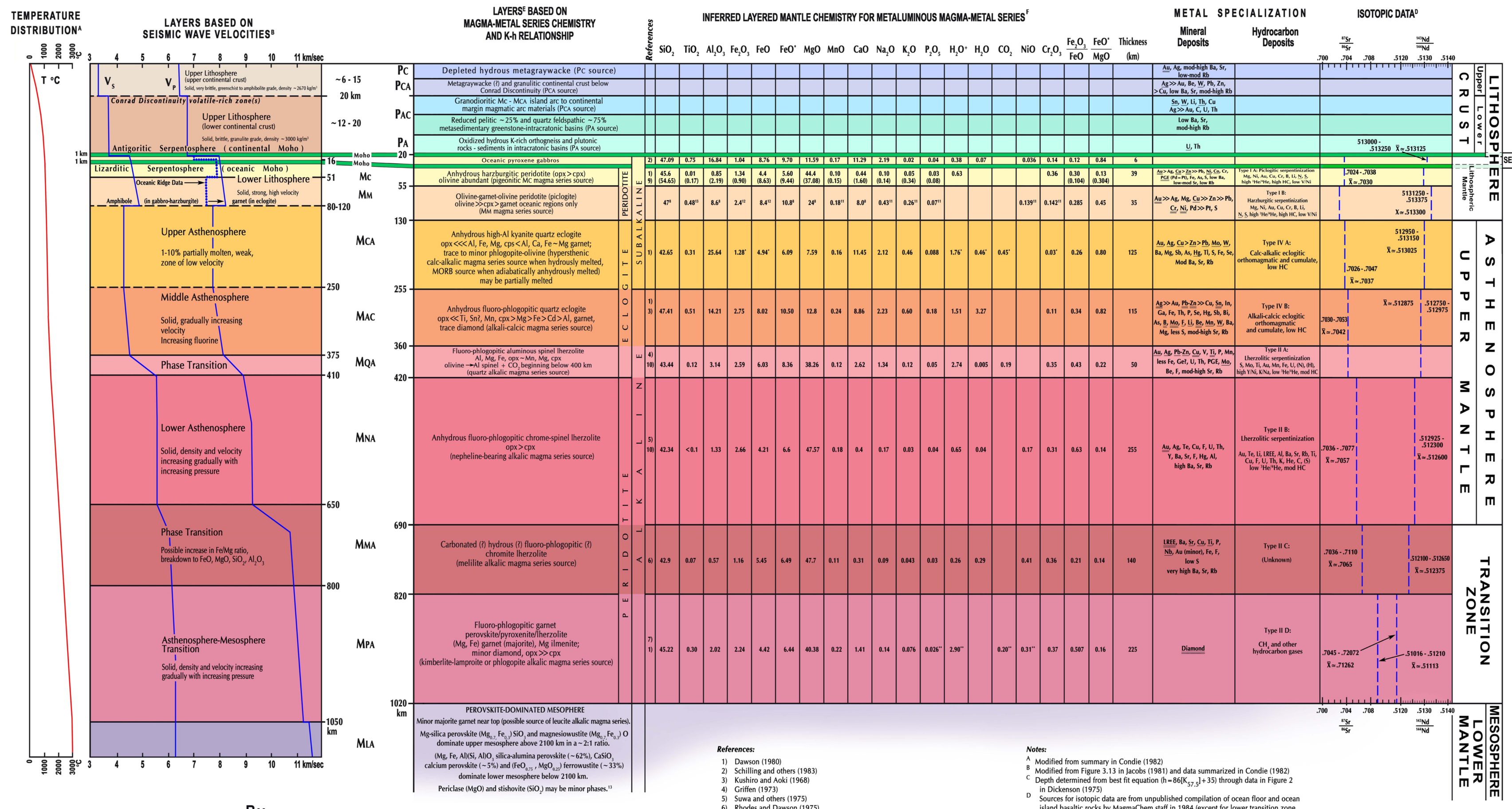


Figure 3. Schematic diagram of the UDH model in flat subduction settings showing development of deep-sourced, hydrocarbon- and magnesium-rich brines formed by serpentinization of flatly subducting, harzburgitic peridotite.

Magma-Metal Series Petrotectonic Model for a Layered Earth



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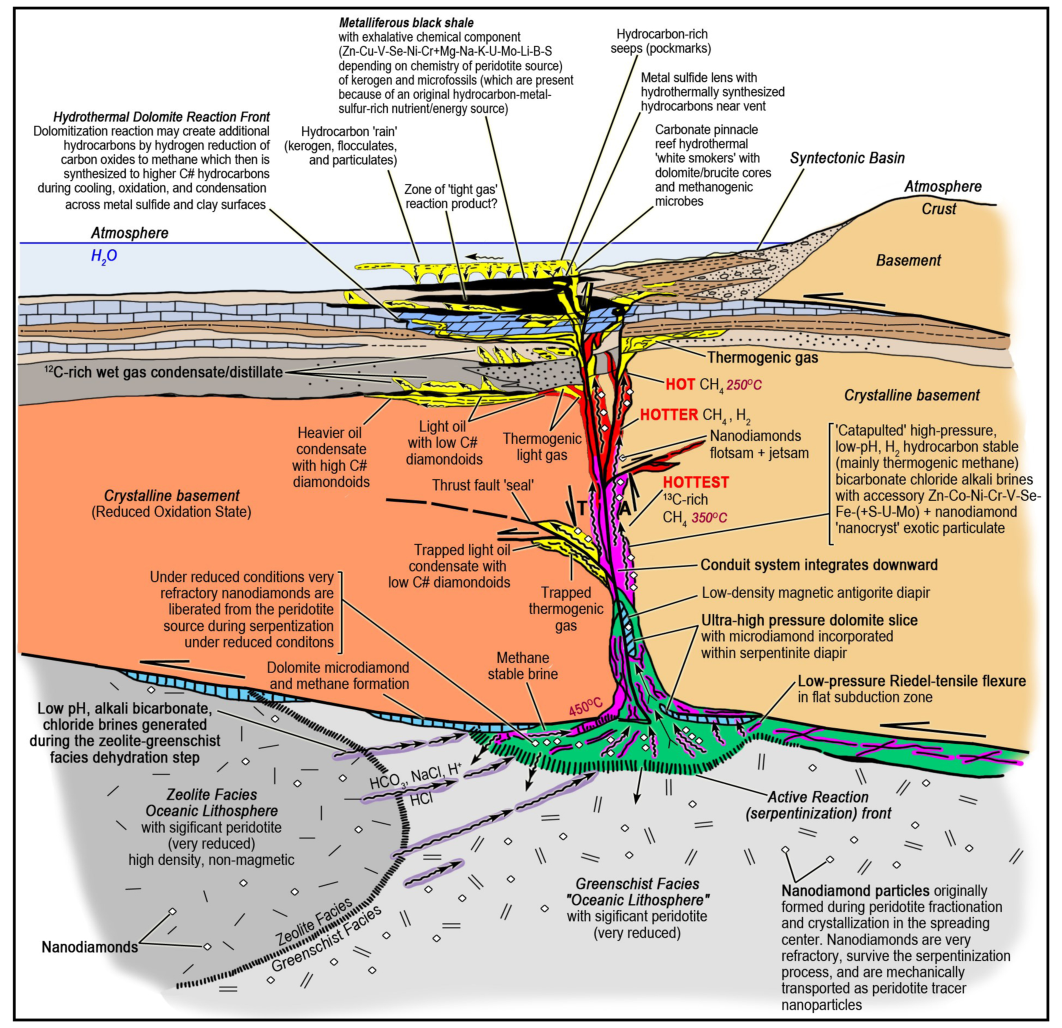

Figure 9. Conceptual Ultra-Deep Hydrocarbon model showing how hydrothermal petroleum results from the serpentinization process (redrawn from Keith and Swan, 2005).

SUMMARY AND CONCLUSIONS

Magma-metal series models were used to characterize mineralization at Yucca Mountain and nearby areas in southwestern Nevada. The assessment was updated with models related to the ultra-deep hydrocarbon (UDH) model, which suggests that oil can be formed hydrothermally via deep-sourced serpentinization processes.

Cretaceous mineralization in the area began with MAC29B lead-zinc-silver deposits at 102 – 99 Ma and later MCA14 porphyry copper-molybdenum tendencies at 93 – 96 Ma. These were followed by PC2 tungsten in pegmatite dikes of Late Cretaceous age and then by PCA3A gold-quartz veins at 85 – 72 Ma. This pattern results from flattening subduction.

Tertiary mineralization includes: MCA gold mineralization at 13.8 – 14.9 Ma; MAC base-metal tin or fluoride mineralization at 12.8 – 11.2 Ma; MQA gold mineralization at 10 Ma; and MNA gold-telluride mineralization at 8 Ma. The increasing alkalinity with decreasing age reflects a rapidly steepening subducting slab beneath the Yucca Mountain area between 15 and 7 Ma.

Magmatism after 7 Ma in the region is not associated with metallic mineralization and occurs as anhydrous, basaltic volcanic cones in Crater Flat. Modern basaltic activity has followed active Basin and Range faulting and has shifted to the west into Death Valley, Owen's Valley, and Panamint Valley.

Hydrothermal activity after 7 Ma could be associated with a possible ultra-deep hydrocarbon (UDH) model. Evidence for a Pliocene-Quaternary hydrothermal event includes coincident gravity lows and magnetic highs in Crater Flat, widespread magnesian calcite and low-temperature hydrothermal activity, and comparisons with features at Railroad Valley.

Magmatism in the Southwest Nevada Volcanic Field probably did not access enough water during early fractionation to develop sufficient volume or chemical characteristics for a highly metal-rich hydrothermal fluid. Dry magmatism (lack of biotite and hornblende) is not associated with large, high-grade metal systems throughout the world. Certain volcanic units are slightly more water-rich and more voluminous than others and are associated with tin mineralization and alteration events. None of the multiple hydrothermal metallic mineralization events at Yucca Mountain itself are younger than approximately 11.4 Ma.

The potential for the existence, exploration, or discovery of economic metallic resources at the Yucca Mountain site is negligible for most commodities. Current markets and those in the foreseeable future are not likely to attract exploration companies to American tin occurrences. Potential for Carlin-type gold deposits may exist below approximately 5,000 feet in Paleozoic sedimentary rocks. However, nearby regions contain much higher potential for discovery of this type of gold deposits in the foreseeable future. Low potential exists for the discovery of mercury deposits. Potential for other metallic commodities, such as silver, copper, molybdenum, lead, zinc, iron, tungsten, antimony, and manganese, is negligible. The Nevada Test Site and Yucca Mountain site are presently restricted from mineral entry and this is not likely to change in the foreseeable future.

ACKNOWLEDGEMENTS

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